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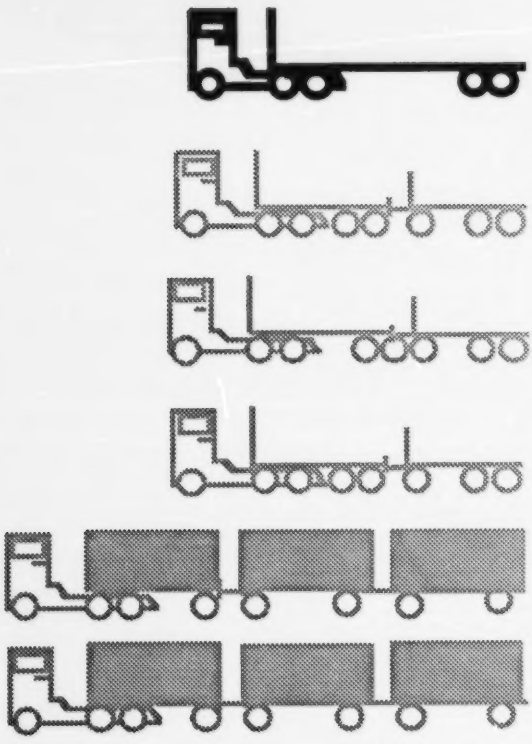
Demonstration of Baseline Vehicle Performance: 45 ft Semi



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Demonstration of Baseline Vehicle Performance: 45 ft Semi

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Prepared for:
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Abstract:
A 45 ft (13.72 m) semitrailer combination was tested by the Ontario Ministry of Transportation and Communications (MTC) as part of the CCMTA/RTAC Vehicle Weight and Dimensions Study. The vehicle was designated a baseline vehicle and the representative test vehicle for similar configurations.

The vehicle was subjected to turning, air brake system, lateral/directional and roll stability, and trailer sway tests. A demonstration of straight-line braking was also conducted. Tests were conducted with the empty vehicle on a low-friction surface and the loaded vehicle on a high-friction surface.

This report presents detailed results of the tests and demonstrations.

Key Words: truck testing, offtracking, truck turning, air brake system, braking, truck dynamic tests, rearward amplification, rollover, lane change, tilt test

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ABSTRACT

A 45 ft (13.72 m) semitrailer combination was tested by the Ontario Ministry of Transportation and Communications (MTC) as part of the CCMTA/RTAC Vehicle Weight and Dimensions Study. The vehicle was designated a baseline vehicle and the representative test vehicle for similar configurations.

The vehicle was subjected to turning, air brake system, lateral/directional and roll stability, and trailer sway tests. A demonstration of straight-line braking was also conducted. Tests were conducted with the empty vehicle on a low-friction surface and the loaded vehicle on a high-friction surface.

This report presents detailed results of the tests and demonstrations.

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1/ INTRODUCTION

The effects of changes in truck weight and dimension parameters on combination vehicle stability and handling and on pavement response to axle group loading are being examined in the CCMTA/RTAC Vehicle Weights and Dimensions Study. The vehicle portion of the study involved both computer simulation of vehicle dynamic manoeuvres and testing of vehicles and components. Combination vehicles were classified into six families, based on the number of trailers and methods of hitching. A representative of each family was designated as the baseline vehicle for that family. Additional vehicle configurations of interest were also defined. All baseline and additional vehicle configurations were tested to assemble a body of technical and visual data that described the stability and control characteristics of the vehicles with respect to certain performance measures.

The Ontario Ministry of Transportation and Communications (MTC) was asked to test the six baseline vehicles and three additional tractor-trailer combinations, as part of its contribution to the study. This report presents the results of a test of a 45 ft (13.72 m) semitrailer combination baseline vehicle. It refers frequently to a report describing procedures and equipment common to tests of all nine vehicles undertaken by MTC [1]. Similar reports present details of the tests of the other eight vehicles [2-9], and a summary report presents the results of tests of all six baseline vehicles [10]. A computer simulation of vehicle responses to actual test inputs using estimated vehicle data has also been conducted [11].

2/ TEST VEHICLE DESCRIPTION

The test vehicle consisted of the MTC Freightliner [1] and a 45 ft (13.72 m) tandem-axle semitrailer. The combination is typical of equipment used in Atlantic and Western Canada and the US. Semitrailers used in Central Canada now typically have a 1.83 m (72 in) or more tandem-axle spread, compared with the 1.37 m (54 in) of this trailer.

The equipment for these tests was provided by the Roads and Transportation Association of Canada (RTAC). No modifications were made to the trailer except for purposes of attachment of test equipment, which had no effect on the operation of the vehicle, though unit weights and polar moments of inertia were affected.

The trailer was manufactured by RAM Highway Trailers of Canada in June 1981 and bore the serial number 381-13648. The trailer had a nominal length of 13.72 m (45 ft) and a nominal width of 2.44 m (96 in). The axle spacing was 1.37 m (54 in). Suspension was a four-spring leaf system with torque rods and equalizers. The spring centre width was 0.96 m (38 in), and the track width was 2.44 m (96 in). The trailer was rated at 8000 kg/axle (17 600 lb). The combination had an overall length of 17.17 m (58.30 ft).

The trailer was fitted with new Michelin XZA radial tires, in load range H and size 11R22.5. These tires were run a nominal distance of 600 km (370 mi) before any testing and were then, subsequently, used for all tests. Tire pressure was set cold at 689 kPa (100 psi), which is the manufacturer's recommended value for full load. This was used for all tests and represents the common operating practice of not reducing tire pressure when running empty.

The test vehicle is shown in Figure 1, in test condition with outriggers installed. The dimensions of the test vehicle are presented in Figure 2. Empty weight of the combination in test condition was 18 299 kg (46 260 lb). Concrete blocks were used to obtain a loaded weight of 31 205 kg (68 650 lb). Axle loads in these conditions are given in Table 1.

Table 1/ Axle Loads

Axle No.	Empty		Loaded	
	(kg)	(lb)	(kg)	(lb)
1	5 009	11 020	5 118	11 260
2	4 209	9 260	6 114	13 450
3	3 791	8 340	6 114	13 450
4	2 472	5 440	6 882	15 140
5	2 818	6 200	6 977	15 350
Total	18 299	40 260	31 205	68 650

The empty weight exceeds that which would normally be seen on the highway, because the tractor is considerably heavier than late-model equipment and because of the weight of test equipment installed, particularly the outriggers. A target axle load of 8000 kg (17 600 lb) was set for all axles except for the steer axle. This was not closely attained. The legal gross weight for the vehicle tested varies between 36 500 and about 41 000 kg (80 300 and 90 200 lb), depending upon the province.

The height of the centre of gravity of the empty trailer sprung mass was estimated as 0.24 m (9.4 in) below the top of the floor. The centre of gravity height was estimated as 0.17 m (6.6 in) above the top of the floor in the loaded condition.

3/ TEST PROGRAM

3.1/ Test Procedures

The test vehicle was prepared for testing in the following way:

1/ A mechanical inspection was carried out, and any necessary repairs or maintenance was done.
2/ Outrigger and safety cable attachments and load block retention sills were installed on the trailer.
3/ Outriggers were installed on the trailer.
4/ The boxes containing instrument packages, power supplies and signal conditioning, other instruments, and cabling were installed.
5/ New tires were installed, and pressures were set.
6/ Other fittings necessary for testing were installed.
7/ Concrete blocks were located on the trailer bed to achieve specified axle loads.
8/ Notes were made from a detailed physical inspection, including an inventory of components and measurement of dimensions.
9/ The MTC tractor was coupled to the trailer.
10/ The combination vehicle was weighed, empty and loaded.
11/ A functional test of the on-board electronics was conducted.
12/ Test runs were made to shake down the vehicle instrumentation and familiarize the test driver with the vehicle's handling characteristics.
13/ Articulation angle between the tractor and trailer was calibrated.
14/ Photographs and video film were taken to record details of the vehicle and test equipment.

The following tests were performed:

- Offtracking
- Right-hand turn
- Channelized right turn
- Air brake system
- Straight-line braking, empty vehicle, low-friction surface
- Evasive manoeuvre, empty vehicle, low-friction surface
- Sinusoidal steer, loaded vehicle, high-friction surface
- Lane change, loaded vehicle, high-friction surface
- Normal straight-line driving
- Steady circular turn, loaded vehicle, high-friction surface

All tests followed standard procedures [1], except as noted.

3.2/ Instrumentation

The instrumentation shown in Table 2 was installed. Brake pressure transducers were only installed in the trailer for the air brake system test, but all other instrumentation was installed for all tests. Data were always captured from all instrumentation, but only those pertinent to a particular test were analysed.

Tractor instruments were selected from the instrumentation that is permanently installed on the tractor. Instruments for the trailer were mounted in a box placed on the trailer deck, which also contained power supplies and signal conditioning. Trailer lateral acceleration and roll angle were measured at a point midway between the kingpin and axle.

Full details of the instrumentation, signal conditioning, and data capture system are presented elsewhere [1].

3.3/ Data Capture and Data Processing

Data were digitized on board the vehicle and transmitted by telemetry as a pulse-code modulated (PCM) data stream to a ground station, where they were recorded on magnetic tape and captured in real time by an HP-1000 computer system. Test data for a run were processed immediately after the run, and results from a series of runs were subsequently analysed using the computer system [1].

Many test runs of all types were conducted for this vehicle. Not all these runs were used in the preparation of this report. In a number of instances, a run failed to meet a test condition.

Table 2/ Instrumentation Installed

No	Measurement	Instrument	Full Scale
1	Tractor steer angle	Spectrol 139 potentiometer	25.02°
2	Tractor roll angle	Humphrey CF18-0907-1 gyro package	8.85°
3	Tractor lateral acceleration	Kistler 303B accelerometer	0.957 g
4	Tractor yaw rate	Humphrey RT03-0502-1 angular rate transducer	38.7°/s
5	Tractor longitudinal acceleration	Kistler 303B accelerometer	0.974 g
6	Tractor speed, axle 1 right	Airpax 087-304-0044 zero velocity magnetic pickup	104.8 km/h
7	Tractor distance, axle 1 right	Airpax 087-304-0044 zero velocity magnetic pickup	56.3 m/ramp
8	Tractor fifth wheel load, left-hand side	MTC load cell	9890 lb
9	Tractor fifth wheel load right-hand side	MTC load cell	10 290 lb
10	Tractor treadle valve pressure	Celesco PLC-200G	100 psi
11	Tractor brake pressure, axle 2 Left	Celesco PLC-200G	99.80 psi
12	Tractor lateral acceleration at fifth wheel	Columbia SA-107 accelerometer	0.996 g
13	Tractor yaw angle	Humphrey CF18-0907-1 gyro package	17.73°
14	Trailer 1 articulation angle	Celesco pull cord DV-301-150	18.361°
15	Trailer 1 lateral acceleration	Columbia SA-107 accelerometer	0.995 g
16	Trailer 1 roll angle	Humphrey VM02-0128-1 vertical gyro	8.90°
17	Trailer 1 outrigger touchdown	Strain gauge bridge	1.0 V
18	Brake pressure, axle 4 right	Celesco PLC-200G	104.96 psi
19	Brake pressure, axle 5 right	Celesco PLC-200G	101.06 psi

4/ RESULTS

4.1/ Offtracking

Steady-state offtracking is considered an indicator of vehicle turning ability. Offtracking of the vehicle was evaluated by making a complete turn around a circle of radius 29.87 m (98 ft). The vehicle outer wheel tracked the inside of the circle. Turns were made in both directions, as shown in Figure 3. At the end of a turn, the vehicle was parked and the radius to each axle was measured, according to the standard test procedure [1].

The results are shown in Table 3. The measured data were averaged for the left and right turn and then compared to data generated by a simple offtracking formula [12]. The difference between actual and computed values shown in the last column of Table 3 is so small that steady-state offtracking can clearly be estimated very accurately by this simple formula.

The final offtracking for the clockwise turn is shown in Figure 4. After averaging for both directions and correcting for differences in axle track width, the offtracking of 2.65 m (8.69 ft), shown in Figure 4, became 2.82 m (9.25 ft).

Table 3/ Offtracking

Axle No.	Track Width (m)	Radius to Inner Wheel		Difference (m)	Average (m)	Calculated (m)	Difference %
		Right Turn (m)	Left Turn (m)				
1	2.31	27.62	27.70	0.08	27.66	27.56	-0.36
2	2.37	27.26	27.39	0.13	27.32	27.21	-0.40
3	2.37	27.22	27.36	0.14	27.29	27.21	-0.29
4	2.37	24.91	25.06	0.15	24 99	24.92	-0.28
5	2.37	24.88	25.03	0.15	24.96	24.92	-0.16

4.2/ Right-Hand Turn

A 90° right-hand turn is a very demanding manoeuvre for a large truck. The vehicle's swept path in a 90° right-hand turn of 15 m (49.2 ft) radius was measured, according to the standard test procedure [1]. This radius is typical in an urban area or where there is limited truck traffic. The swept path is shown in Figure 5.

The vehicle is shown in Figure 6 during the turn. The maximum excursion out of lane was 2.20 m (7.22 ft), just over half a lane width. It was out of the exit lane for a distance of 19.20 m (63.0 ft), as derived from Figure 5. This test was conducted at a creep speed and represents about the best possible turn. A rolling turn would probably result in a greater excursion out of the exit lane.

4.3/ Channelized Right Turn

The vehicle's swept path in a channelized right turn was measured according to the standard test procedure [1].

The vehicle is shown during the turn in Figure 7. The clearance of the innermost wheel of the rear trailer's rear axle from the inner curb is shown in Figure 8 as a function of distance through the curve. The minimum clearance was only 0.89 m (35 in) in the 5.5 m (18 ft) wide roadway.

The roadway geometry used for this test is typical of an urban area, where space is limited. The curb radius was 25 m (82 ft), and entry and exit tapers typical of four-lane roadways with a 60 km/h speed limit were used. The vehicle easily made it through the channel. The test was run at creep speed, the worst condition, as the effect of lateral acceleration is to reduce the geometric offtracking measured in this test.

4.4/ Air Brake System

The air brake system of the combination was evaluated according to standard test procedure [1].

The trailer air brake system was inspected. A schematic of the system is shown in Figure 9. All slack adjusters required manual adjustment. Stroke was adjusted to the minimum, about 32 mm (1.25 in) on each axle. The tractor was supplied with shop air, regulated at 689 kPa (100 psi). Pressure transducers were installed at both trailer axles.

The SAE J982a style test was performed for the full combination. The results of this test, presented in Table 4, are the average of several tests, each with a time resolution of 0.02 s. The application and release times of this test are typical of such equipment. A typical time history response of application and release is presented in Figure 10.

Table 4/ Air Brake Timing, SAE J982a Style Test

Location	Application Timing 0-60 psi (s)	Release Timing to 5 psi (s)	Final Pressure (psi)
Treadle	0.07	0.19	99.2
Axle 2	0.41	0.64	98.8
Axle 4	0.49	0.94	96.2
Axle 5	0.45	0.88	97.6

4.5/ Straight-Line Braking

It is difficult to conduct rigorous braking tests and achieve consistent results. A demonstration of modes of instability of the combination vehicle in straight-line braking was, therefore, conducted. A series of runs was made with the empty vehicle approaching the low-friction test area at 47 km/h and the driver braking using the treadle valve. Runs were made using various application pressures, to the point where groups of wheels locked. The driver was instructed not to attempt to counter any loss of control, except as necessary to avoid hazard. The standard test procedure was followed [1].

The vehicle combination was evaluated primarily in terms of the yaw response of vehicle units, which is the heading angle of the vehicle unit (in degrees), with zero parallel to the original direction of travel. Any significant yaw seen in this manoeuvre arose from lateral/directional instability of a vehicle unit.

The time history of a typical run that resulted in loss of control is shown in Figure 11. The initial average brake application of 311 kPa (45 psi) caused all brake wheels to lock, and the tractor jackknifed to the right. The driver reduced the brake pressure, as a consequence, and steered a little to the left, in controlled instinctive responses. The tractor, however, continued to rotate until the safety cables were engaged, as seen from the 15° limitation on articulation angle, and the vehicle rotated as a unit. The tractor heading reached the limit of the signal conditioning system. If the front axle brakes on the tractor had been used, it is likely that there would not have been a tractor jackknife. The vehicle final position is shown in Figure 12.

A summary of peak vehicle responses from the runs is shown in Figure 13 as a function of average treadle valve pressure over the entire stop.

The limit of surface adhesion of about 0.15 g was reached at about 159 kPa (23 psi), when most wheels were locking, but it was not until a significantly greater pressure that the vehicle actually became unstable. That point is seen in Figure 13 at about 221 kPa (32 psi) because of the averaging, although it was the much higher initial pressure that caused the instability.

4.6/ Evasive Manoeuvre

The object of this test was to evaluate empty vehicle lateral/directional characteristics at the limits of stability on a low-friction surface. A series of runs was made where the driver made an evasive manoeuvre, which is considered representative of a high-speed accident avoidance situation on a two-lane, two-way highway. The test used gates of 22.5 m (73.8 ft) for the lane change to the left and the return to the original lane, separated by 20 m (65.6 ft) in the left lane. The runs were made in accordance with the standard test procedure [1].

The vehicle combination was evaluated primarily in terms of the lateral acceleration and yaw responses of the vehicle units. These are shown in Figure 14. Each response is the peak-to-peak amplitude experienced by the vehicle in the manoeuvre. The lateral acceleration amplitude of tractor and trailer both increased to 5 to 5.5 m/s^2 near 56 km/h, where they tended to level off. It was evident from these data, driver reports, and observation that the tractor was close to the limits of adhesion, making it difficult to manoeuvre. The tractor and trailer heading angle remained uniform, indicating that although the driver had partial steer control, he was able to maintain directional control. Run data indicated that the driver had to increase steer angle as speed increased, implying an increase in tractor understeer. Tractor control appeared to be the limiting factor for this vehicle in this manoeuvre.

The driver was able to make this manoeuvre up to 60 km/h. At 63 km/h he was unable to get the vehicle through the gate to return to the original lane, due to the limit on the tractor control and the length of the vehicle. While the objective of the manoeuvre was not achieved, the vehicle was not sliding substantially. No higher speed was attempted. A typical run at 63 km/h is shown in Figure 15.

4.7/ Sinusoidal Steer

The objective of this test was to evaluate characteristics of rearward amplification of lateral acceleration for this combination. A series of runs was made where the driver made a sinusoidal steer input to the vehicle while travelling at a steady speed, in accordance with the standard test procedure [1]. This test was conducted at speeds of 63, 84, and 94 km/h, with steer input periods between about 2 and 5 s.

The vehicle combination was evaluated in terms of lateral acceleration responses of the trailer. Rearward amplification of lateral acceleration is presented in Figure 16, as a function of tractor steer input period, for the three test speeds. This is defined as the peak-to-peak trailer lateral acceleration response divided by the peak-to-peak tractor lateral acceleration, and is dimensionless [1].

It is evident from Figure 16 that rearward amplification remains relatively constant with respect to both speed and steer period. Its maximum value is about 1.50. Even at highway speed, the 45 ft (13.72 m) semi is a very stable vehicle, because of its low response to input.

Figure 17 shows the vehicle response from a typical run for a steer period of about 2 s at 94 km/h.

4.8/ Lane Change

The objective of this test was to evaluate vehicle stability characteristics in a dynamic manoeuvre. A series of runs was made where the driver made a lane-change manoeuvre, which is considered representative of a high-speed accident avoidance situation on a four-lane or divided highway. The runs were made in accordance with the standard test procedure [1].

The test used a gate of 30 m (98.4 ft) for the lane change. This was used to provide a vehicle speed of about 80 km/h, which is a typical speed limit and might permit some comparison of the results of this test with those described in the preceding sections. The vehicle is shown in this manoeuvre in Figure 18.

The results from all runs are summarized in Figure 19. The peak-to-peak lateral acceleration, roll, and yaw (or heading) angles all show an increase as the speed climbs. Lateral acceleration and roll gains

are also shown in Figure 19. The lateral acceleration gains at 63, 84, and 94 km/h are consistent with those from the sinusoidal steer test. Lateral acceleration lag time shows some scatter at the higher speeds, indicating possible tractor slide within the lane, but is simply due to the length of the vehicle and, in this case, is not considered to be a gauge of the driver's control of the vehicle. The yaw overshoot of the trailer clearly shows little or no rear trailer swing. Figure 20 shows the steer input and vehicle response from a typical run at 94.8 km/h, the highest speed achieved. Both units were tracking close to each other with no sign of unstable behaviour or excessive roll.

4.9/ Normal Straight-Line Driving

The objective of this test was to attempt to evaluate lateral motion of the rear trailer of the combination, the phenomenon known as trailer sway. A series of runs was made with the loaded vehicle driven normally at 94 km/h in a straight line, according to the standard test procedure [1].

As previously mentioned, the vehicle was quite stable, and the slight steer corrections made in the course of normal driving, and roughness of the test track surface, resulted in no perceptible trailer sway to the occupants of a chase vehicle. Root mean square (RMS) lateral acceleration of the rear trailer was 0.63 g/° of steer input. RMS sway of the rear of the rear trailer relative to the tractor steer axle was 175 mm/° (7 in/°) of RMS steer input. The latter value is suspect because of the very small articulation angle.

4.10/ Steady Circular Turn

The objective of this test was to evaluate vehicle steady-state rollover characteristics, to determine the high-speed offtracking of the vehicle and to examine the side loads exerted on the tractor by the trailer. A series of runs was made with the vehicle circumscribing a circle with a 50 m (164 ft) radius at a steady speed, according to the standard test procedure [1].

The vehicle was evaluated primarily in terms of the roll response of the vehicle units. Average steady-state roll angle is presented in Figure 21 as a function of tractor lateral acceleration and is seen to increase with speed. At the limiting speed of 55 km/h, a peak lateral acceleration of 0.52 g, the trailer outrigger touched down rather gently, as

shown in Figures 22 and 23. The trailer is clearly twisted in Figure 23, due to the distribution of the load. The tractor drive axles did not noticeably lift, so the vehicle was somewhat short of rollover.

The average steady-state articulation angle is shown in Figure 21. These angles decrease modestly with increase in lateral acceleration, and as a consequence, the offtracking decreases.

The lateral force experienced by the tractor fifth wheel is shown in Figure 21, as a function of tractor lateral acceleration. This shows a gradient of 50.8 kN/g (11 400 lb/g).

A tilt table test was conducted on this vehicle, as shown in Figure 24. It revealed 100% lateral load transfer on the high-side wheels at about 28.5°. The tangent of this roll angle should be equal to the lateral acceleration, in g, required to roll the vehicle in the steady circular turn. The tangent of the tilt table was 0.54, whereas the peak lateral acceleration of the trailer at outrigger touchdown was 0.61 g. The tilt test is treated in detail elsewhere [13].

5/ DISCUSSION

Tests were conducted with the equipment as provided. No efforts were made to modify the equipment, except as required for testing, and these modifications did not affect vehicle operation.

Tests were conducted in various weather conditions. Tires wore progressively as the various tests were conducted. The outrigger assembly was additional to normal trailer equipment, and the characteristics of the trailer was, therefore, somewhat atypical, in both empty and loaded conditions. In both conditions, the centre of gravity was somewhat lower than normal because of the underslung outriggers.

It is not possible to make any meaningful remarks on the effect these factors might have had on the results, except for centre of gravity height. The typical 45 ft (13.72 m) semi is a van, which may, when loaded, have a trailer mass centre of gravity up to 1.20 m (4 ft) above the trailer floor, compared to the 0.17 m (6.6 in) for this vehicle. The effect of a raised centre of gravity would have been to reduce the vehicle's roll threshold from 0.54 g observed in the tilt test to, perhaps, 0.25 to 0.30 g [14]. This would have reduced the limiting speed in the steady circular turn and resulted in dynamic rollover in the lane change, as the vehicle lateral acceleration of both vehicle units reached 0.38 g in this manoeuvre. The results presented pertain to the particular vehicle tested, and results different in some respects might be obtained for another vehicle at another time.

This vehicle was considered an easy vehicle to drive by the test driver. It tracked well and was easy to manoeuvre, as the trailer imposed rather modest forces on the tractor. Its length simply meant that it required space to manoeuvre, and in particular, this made the evasive manoeuvre a difficult task, even though the vehicle had not reached its stability limit. It exhibited high stability in all dynamic manoeuvres.

6/ CONCLUSIONS

A 5-axle 45 ft (13.72 m) semi was tested by the Ontario Ministry of Transportation and Communications, as part of the CCMTA/RTAC Vehicle Weights and Dimensions Study. The vehicle was designated a baseline vehicle and the representative test vehicle for similar configurations.

The vehicle was subjected to turning, air brake system, lateral/directional and roll stability, and trailer sway tests. A demonstration of straight-line braking was also conducted. Tests were conducted with an empty vehicle on a low-friction surface and a loaded vehicle on high-friction surface.

The length of this vehicle contributed to the significant space required to make turns.

The air brake system was typical of such vehicles.

The lateral/directional stability of the vehicle was excellent, both empty on a low-friction surface and loaded on a high-friction surface. The roll stability was high because the centre of gravity of the trailer was very low. A higher centre of gravity would have reduced the roll threshold significantly.

7/ REFERENCES

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[2] Billing, J.R., and Mercer, W., "Demonstration of Baseline Vehicle Performance: A-Train Double," Ontario Ministry of Transportation and Communications, Transportation Technology and Energy Branch, Report CV-86-03, June 1986.

[3] Billing, J.R., and Mercer, W., "Demonstration of Baseline Vehicle Performance: B-Train Double," Ontario Ministry of Transportation and Communications, Transportation Technology and Energy Branch, Report CV-86-04, June 1986.

[4] Billing, J.R., and Mercer, W., "Demonstration of Baseline Vehicle Performance: C-Train Double," Ontario Ministry of Transportation and Communications, Transportation Technology and Energy Branch, Report CV-86-05, June 1986.

[5] Billing, J.R., and Mercer, W., "Demonstration of Baseline Vehicle Performance: A-Train Triple," Ontario Ministry of Transportation and Communications, Transportation Technology and Energy Branch, Report CV-86-06, June 1986.

[6] Billing, J.R., and Mercer, W., "Demonstration of Baseline Vehicle Performance: C-Train Triple," Ontario Ministry of Transportation and Communications, Transportation Technology and Energy Branch, Report CV-86-07, June 1986.

[7] Billing, J.R., and Mercer, W., "Demonstration of Tractor-Trailer Performance: 5-Axle 48 ft Semi," Ontario Ministry of Transportation and Communications, Transportation Technology and Energy Branch, Report CV-86-08, June 1986.

[8] Billing, J.R., and Mercer, W., "Demonstration of Tractor-Trailer Performance: 6-Axle 48 ft Semi," Ontario Ministry of Transportation and Communications, Transportation Technology and Energy Branch, Report CV-86-09, June 1986.

[9] Billing, J.R., and Mercer, W., "Demonstration of Tractor-Trailer Performance: 7-Axle 48 ft Semi," Ontario Ministry of Transportation and Communications,Transportation Technology and Energy Branch, Report CV-86-10, June 1986.

[10] Billing, J.R., "Summary of Tests of Baseline Vehicle Performance," Ontario Ministry of Transportation and Communications, Transportation Technology and Energy Branch, Report CV-86-12, June 1986.

[11] Lam, C.P., and Billing, J.R., "Comparison of Simulation and Test of Baseline and Tractor-Trailer Vehicles," Ontario Ministry of Transportation and Communications, Transportation Technology and Energy Branch, Report CV-86-11, June 1986.

[12] Heald, K., "Use of the WHI Offtracking Formula," Paper Presented at Transportation Research Board Symposium of Geometric Design for Large Trucks, Denver, Colorado, August 1985.

[13] Delisle, G., "Investigating Articulated Vehicle Roll Stability Using a Tilt Table," Centre de Recherche Industrielle du Quebec, Report No. 645-19168, June 1986.

[14] Ervin, R.D., Nisonger, R.L., MacAdam, C.C., and Fancher, P.S., "Influence of Size and Weight Variables on the Stability and Control Properties of Heavy Trucks," University of Michigan Transportation Research Institute, Report UMTRI-83-10 (3 volumes), March 1983.

Figure 1/ 45 ft Semi, View of Vehicle

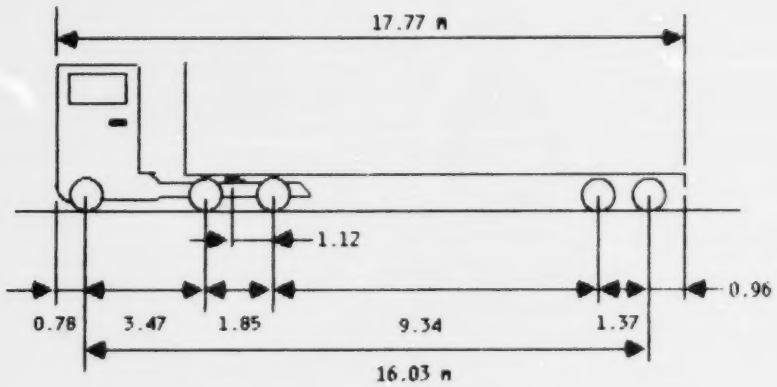


Figure 2/ 45 ft Semi, Vehicle Dimensions

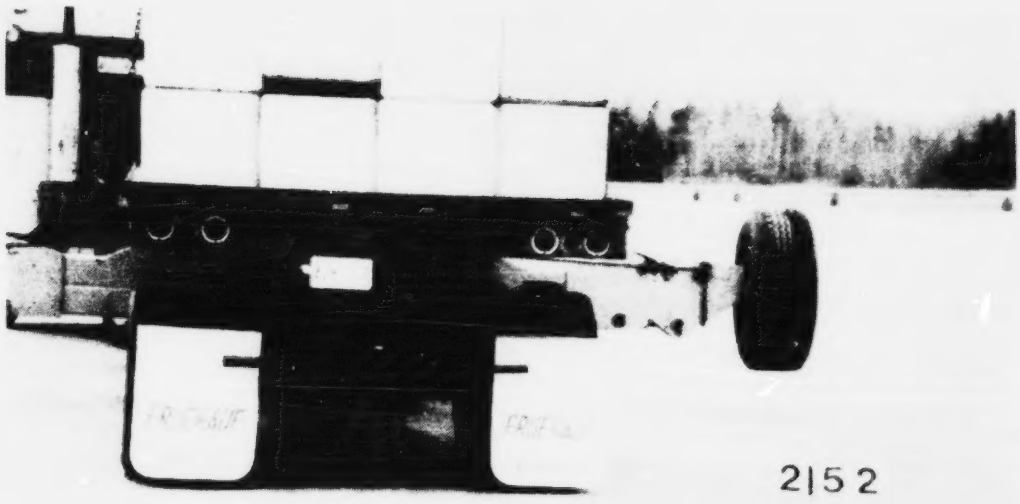


Figure 3/ 45 ft Semi,
Counter-Clockwise Offtracking

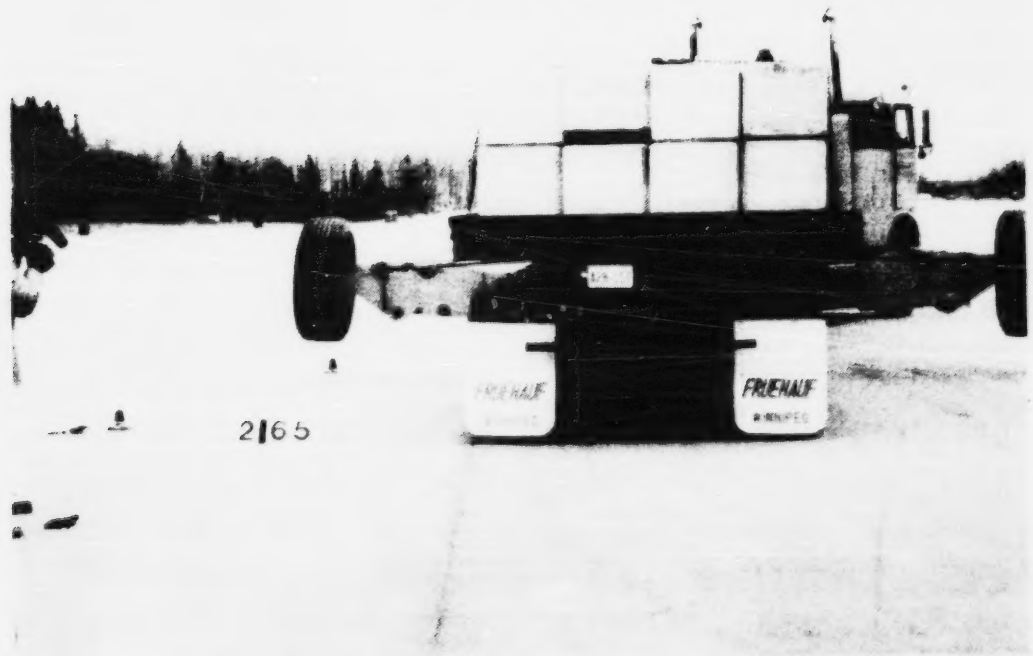
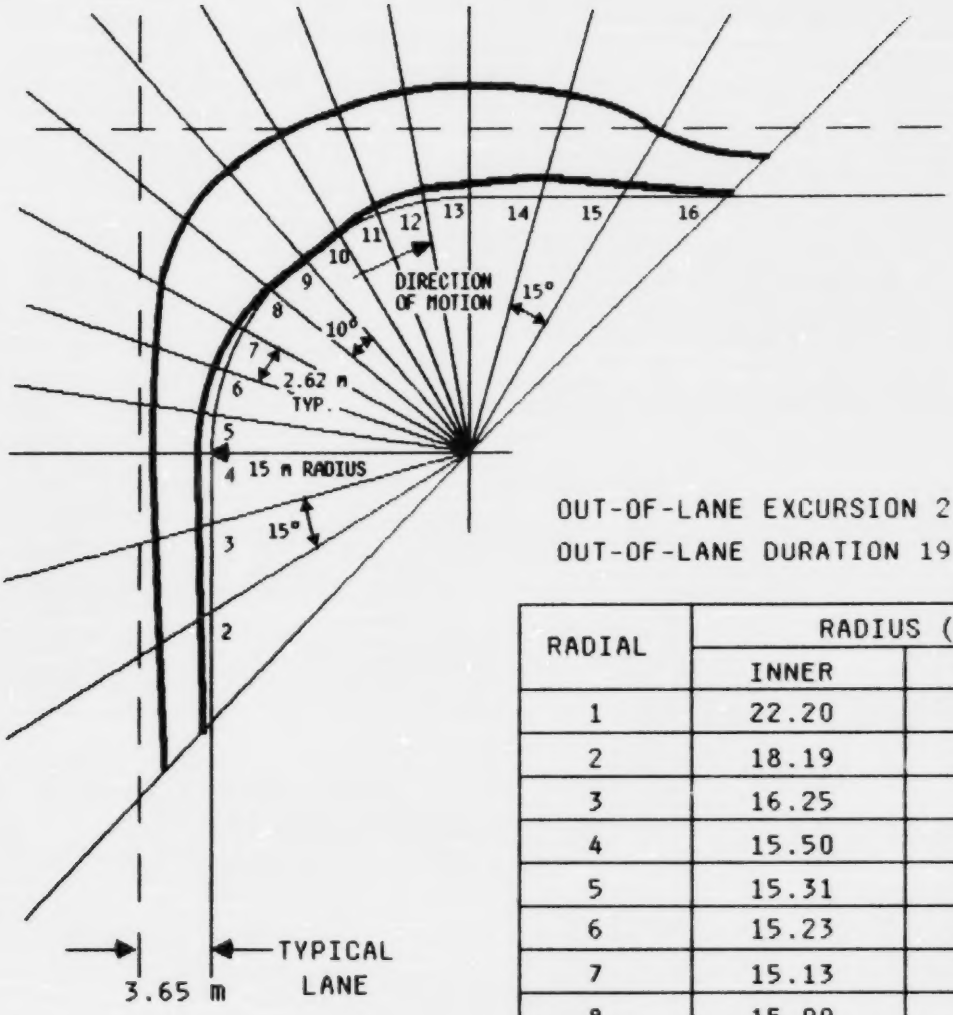


Figure 4/ 45 ft Semi,
Clockwise Final Offtracking



OUT-OF-LANE EXCURSION 2.2 m

OUT-OF-LANE DURATION 19.2 m

RADIAL	RADIUS (m)	
	INNER	OUTER
1	22.20	25.30
2	18.19	20.78
3	16.25	18.74
4	15.50	18.11
5	15.31	18.38
6	15.23	19.07
7	15.13	20.23
8	15.00	20.98
9	15.00	20.38
10	15.00	20.99
11	15.29	20.61
12	15.50	20.46
13	15.65	21.26
14	16.22	21.82
15	17.95	21.74
16	21.62	24.40

Figure 5/ 45 ft Semi, Right-Hand Turn Swept Path

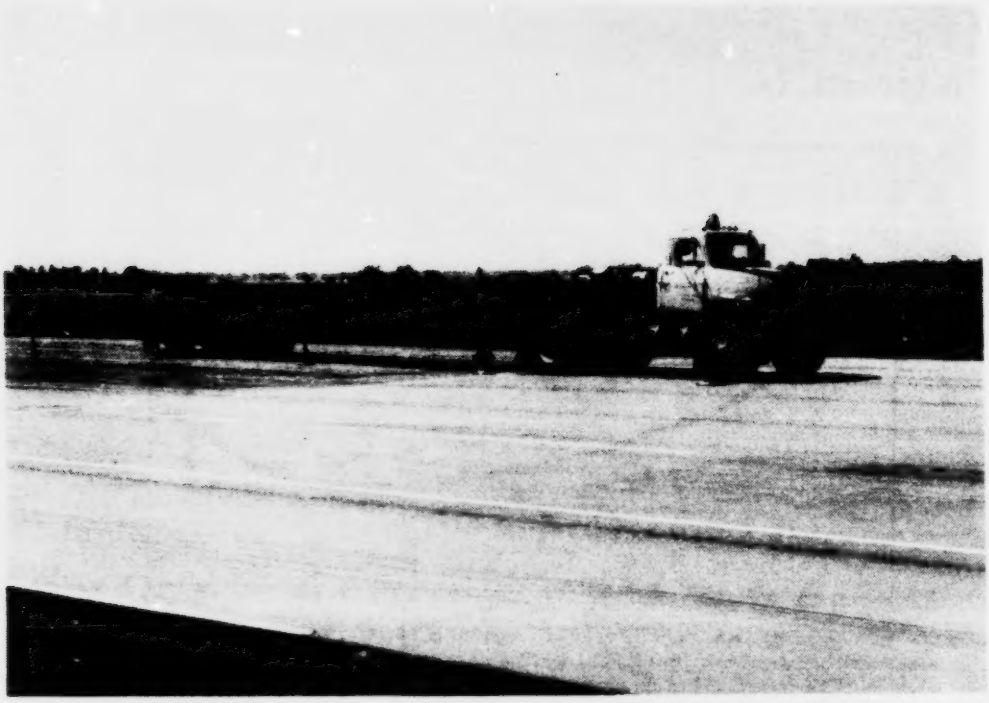


Figure 6/ 45 ft Semi, Right-Hand Turn

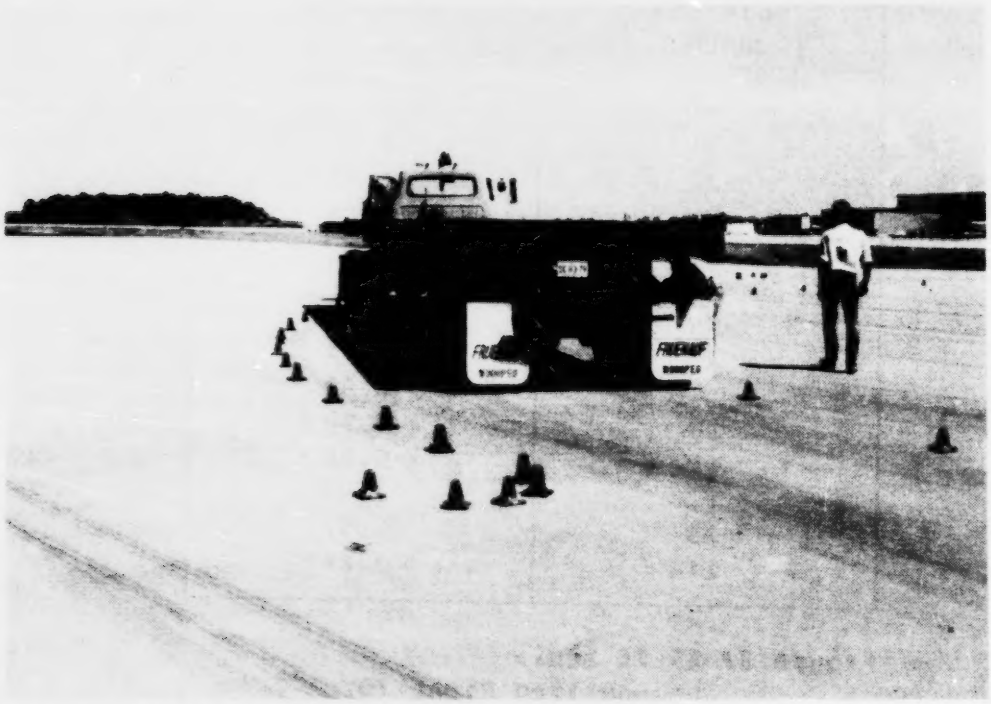
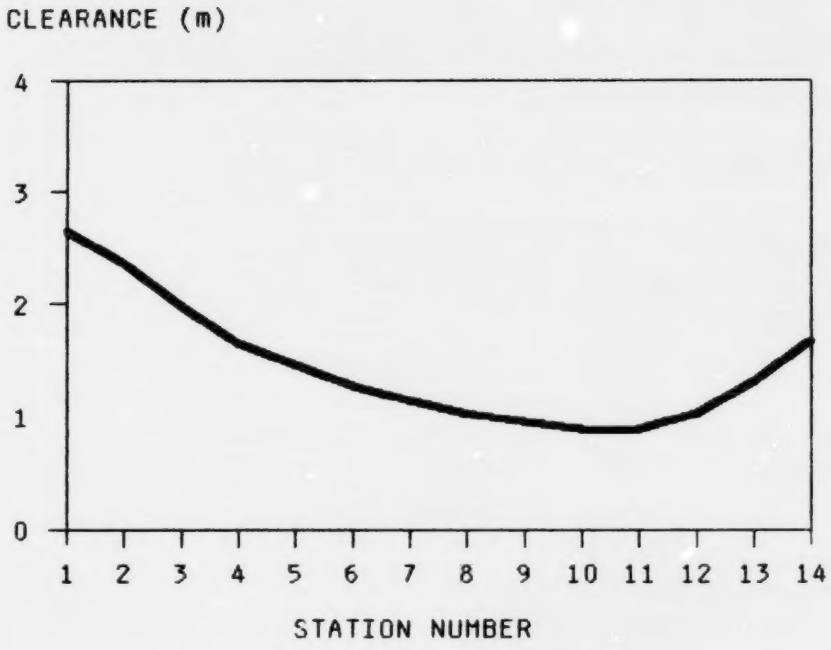


Figure 7/ 45 ft Semi, Channelized Right Turn



STATION NUMBER	CLEARANCE (m)
1	2.64
2	2.37
3	1.97
4	1.66
5	1.45
6	1.27
7	1.15
8	1.04
9	0.97
10	0.90
11	0.89 *(LOW)
12	1.04
13	1.31
14	1.68

**Figure 8/ 45 ft Semi,
Channelized Right-Turn
Clearance from Inner Curb**

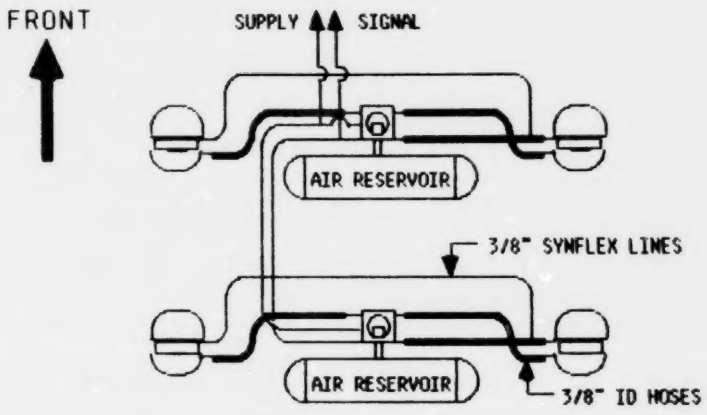


Figure 9/ 45 ft Semi,
Air Brake System Schematic

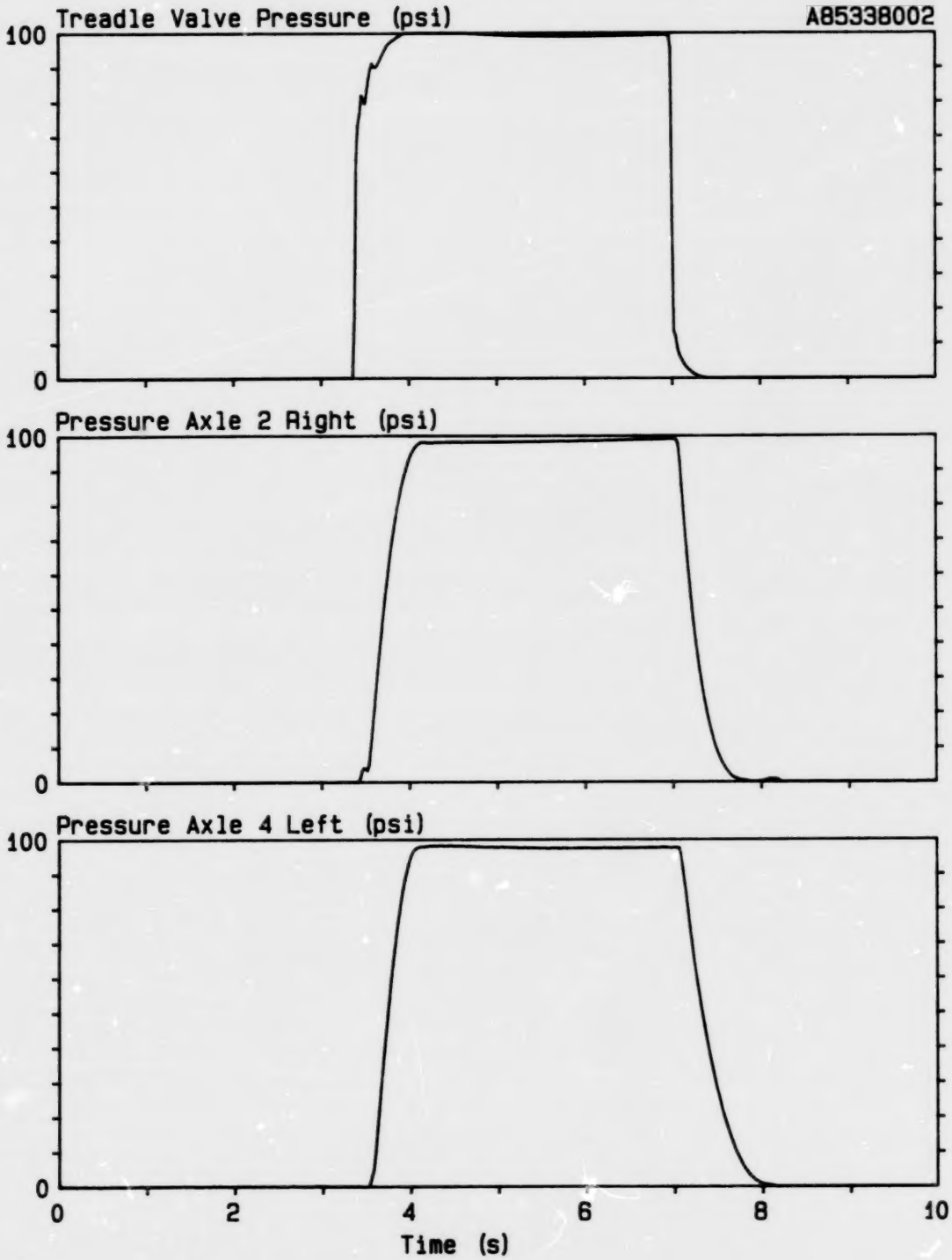


Figure 10/ 45 ft Semi,

Air Brake Application and Release

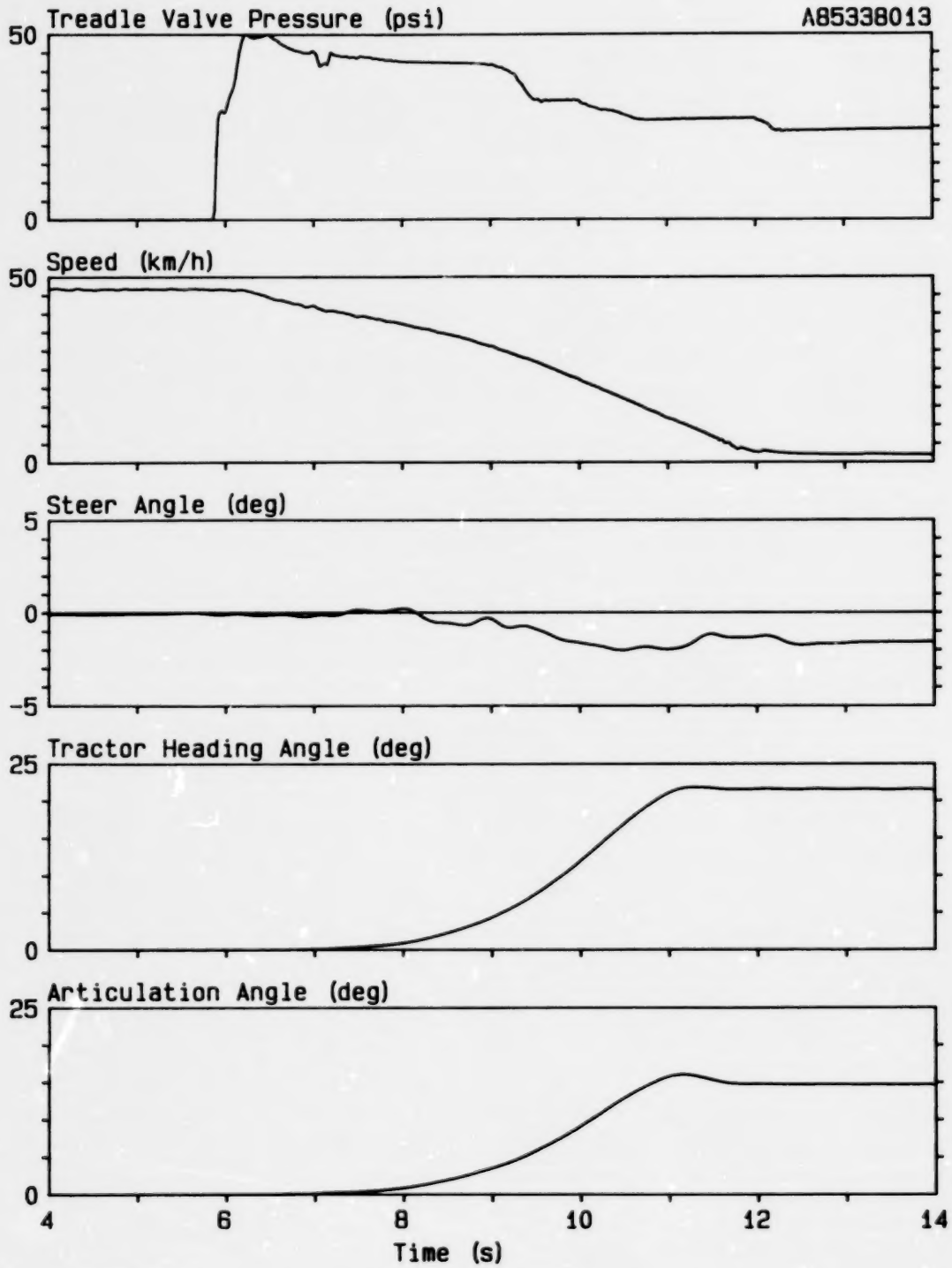


Figure 11/ 45 ft Semi,

Vehicle Response to Straight-Line Braking

Figure 12/ 45 ft Semi, Vehicle Final Position in Straight-Line Braking

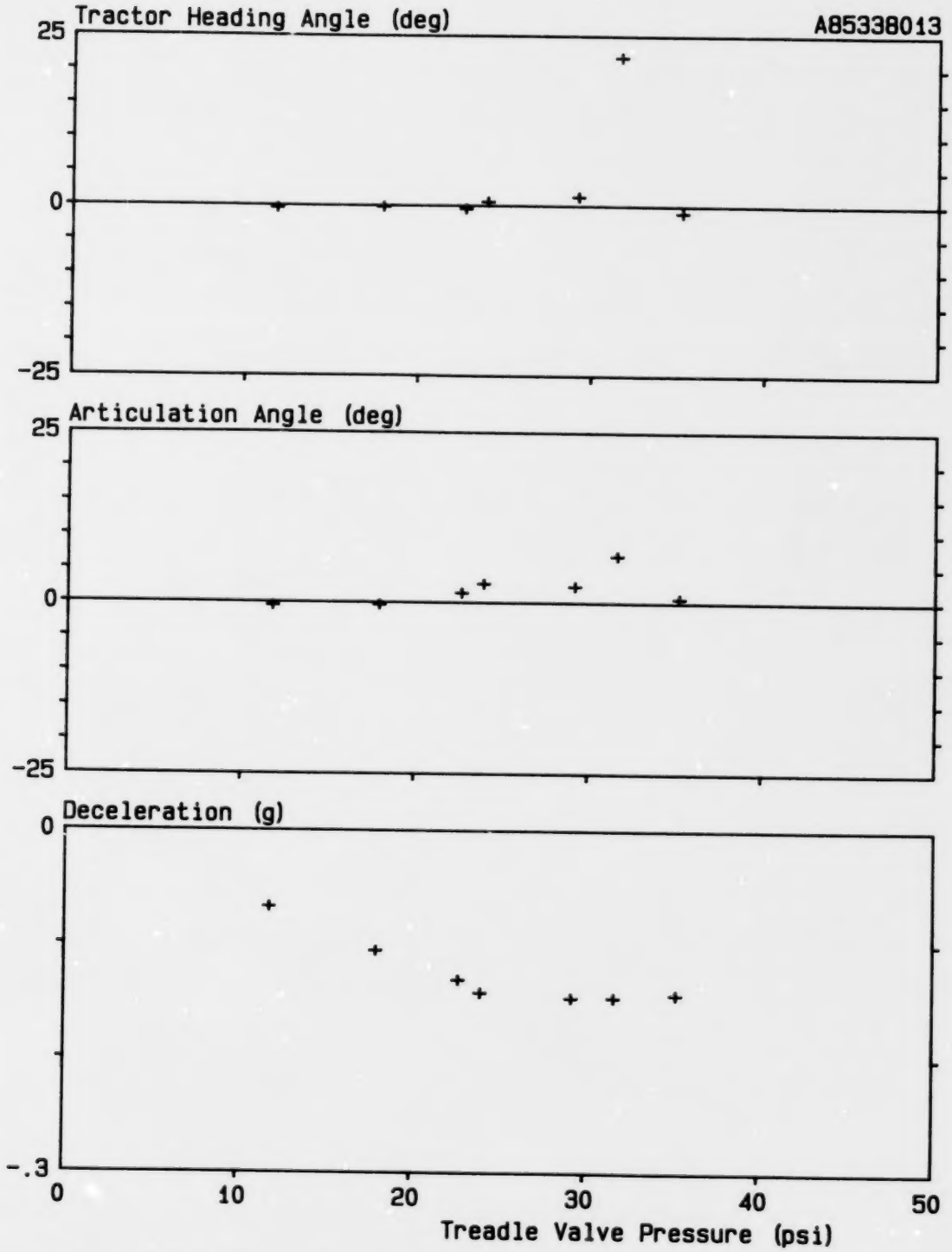


Figure 13/ 45 ft Semi, Straight-Line Braking Responses vs Treadle Valve Pressure

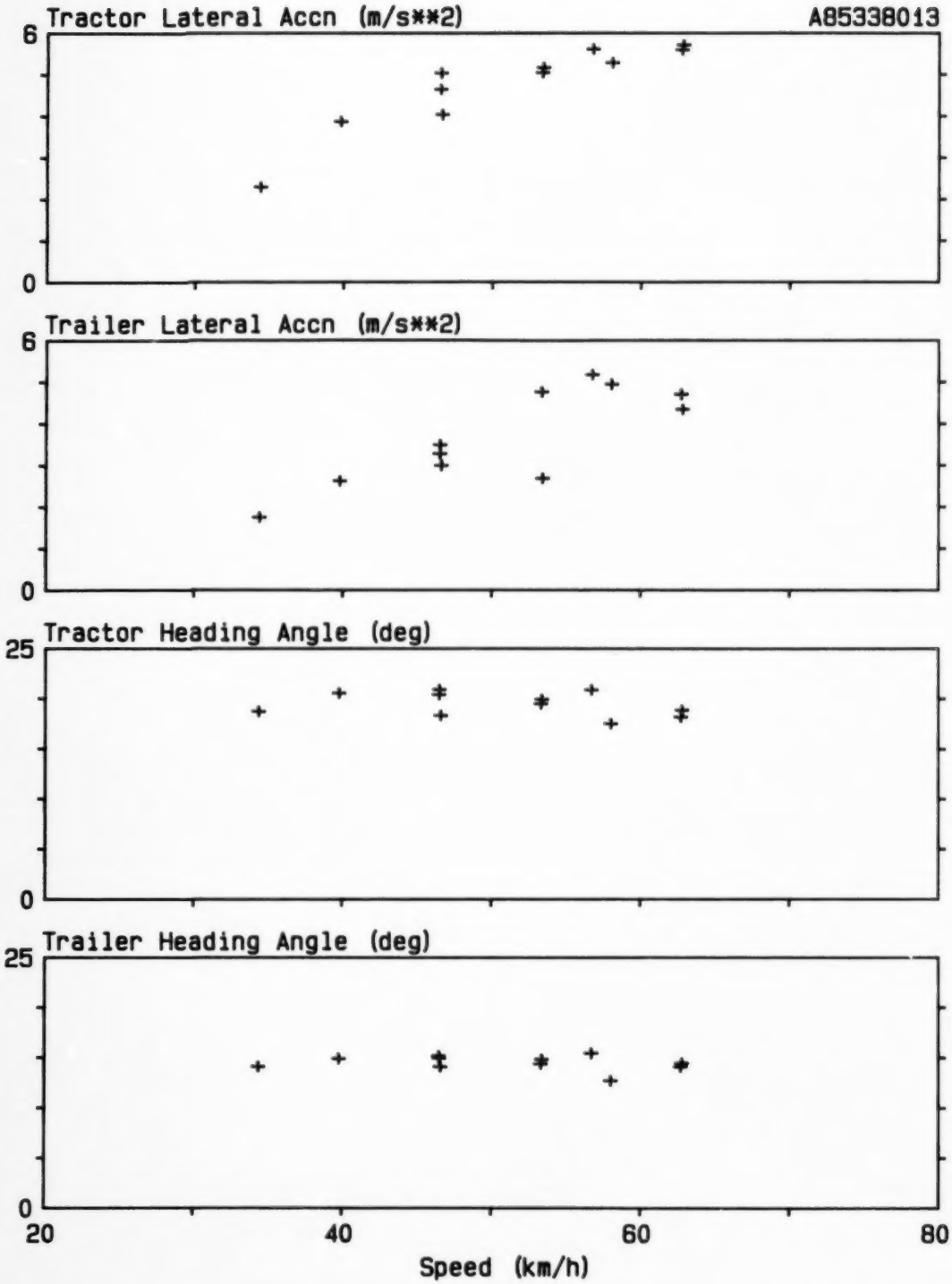


Figure 14/ 45 ft Semi, Evasive Manoeuvre,
Peak-to-Peak Responses vs Speed

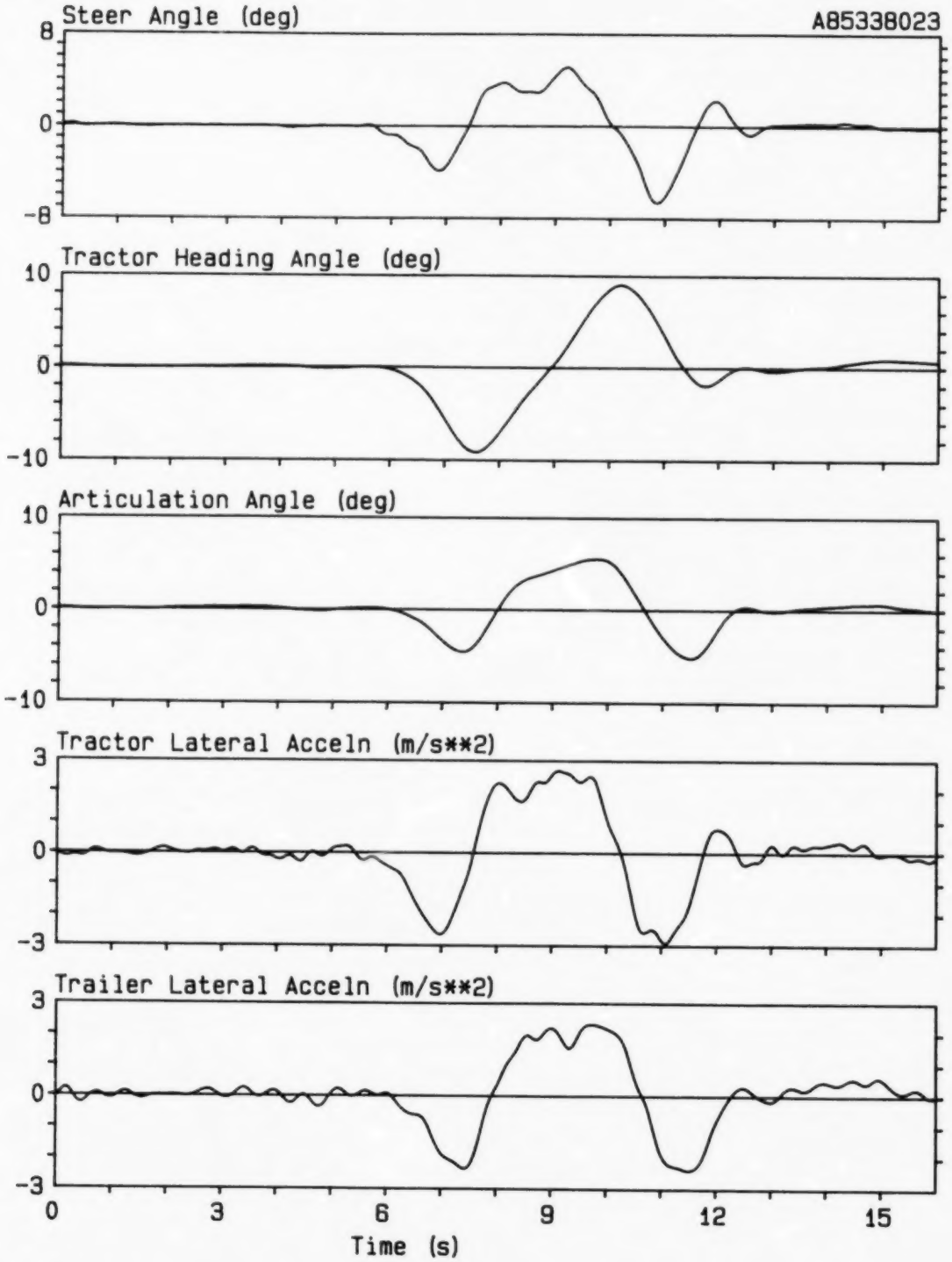


Figure 15/ 45 ft Semi,

Vehicle Response in Evasive Manoeuvre

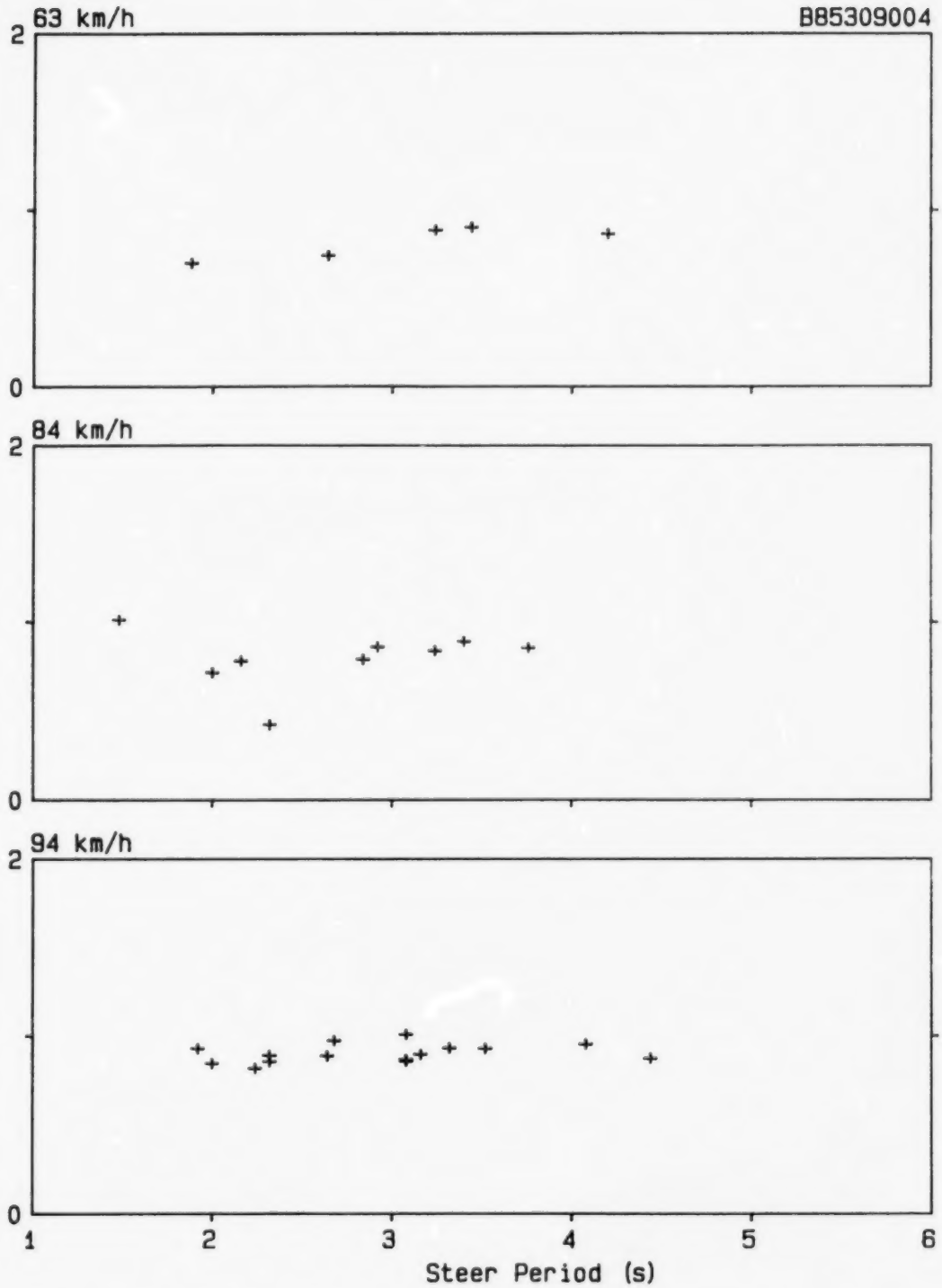


Figure 16/ 45 ft Semi,

Rearward Amplification of Lateral Acceleration

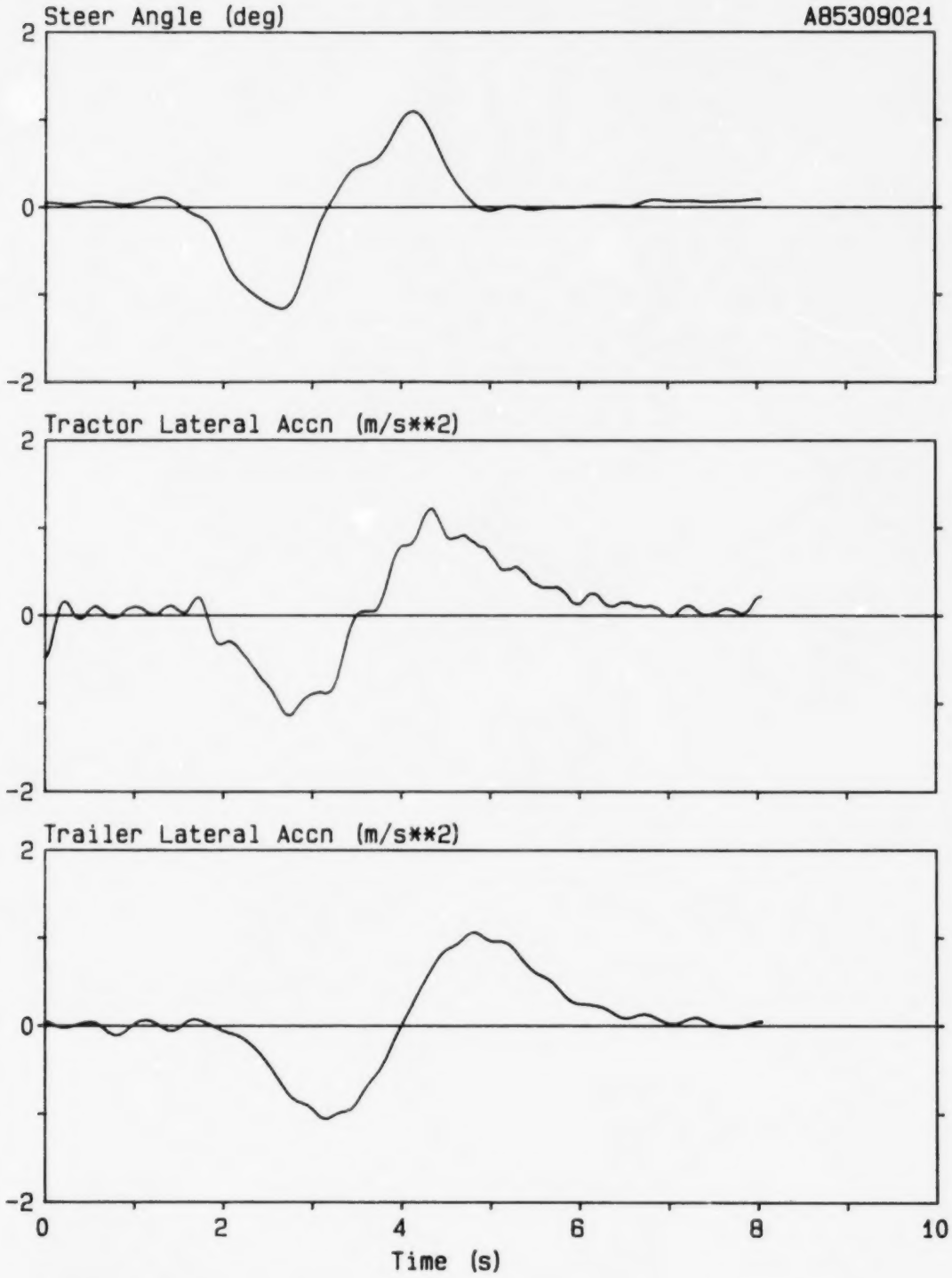


Figure 17/ 45 ft Semi,

Vehicle Response to Sinusoidal Steer at 94 km/h

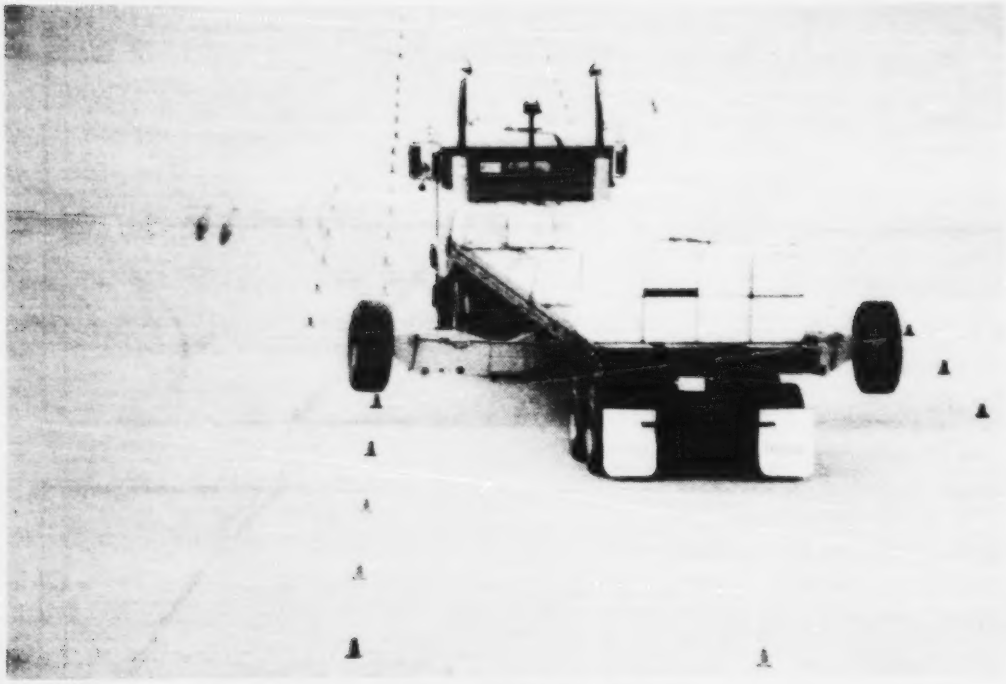


Figure 18/ 45 ft Semi Vehicle Making Lane Change

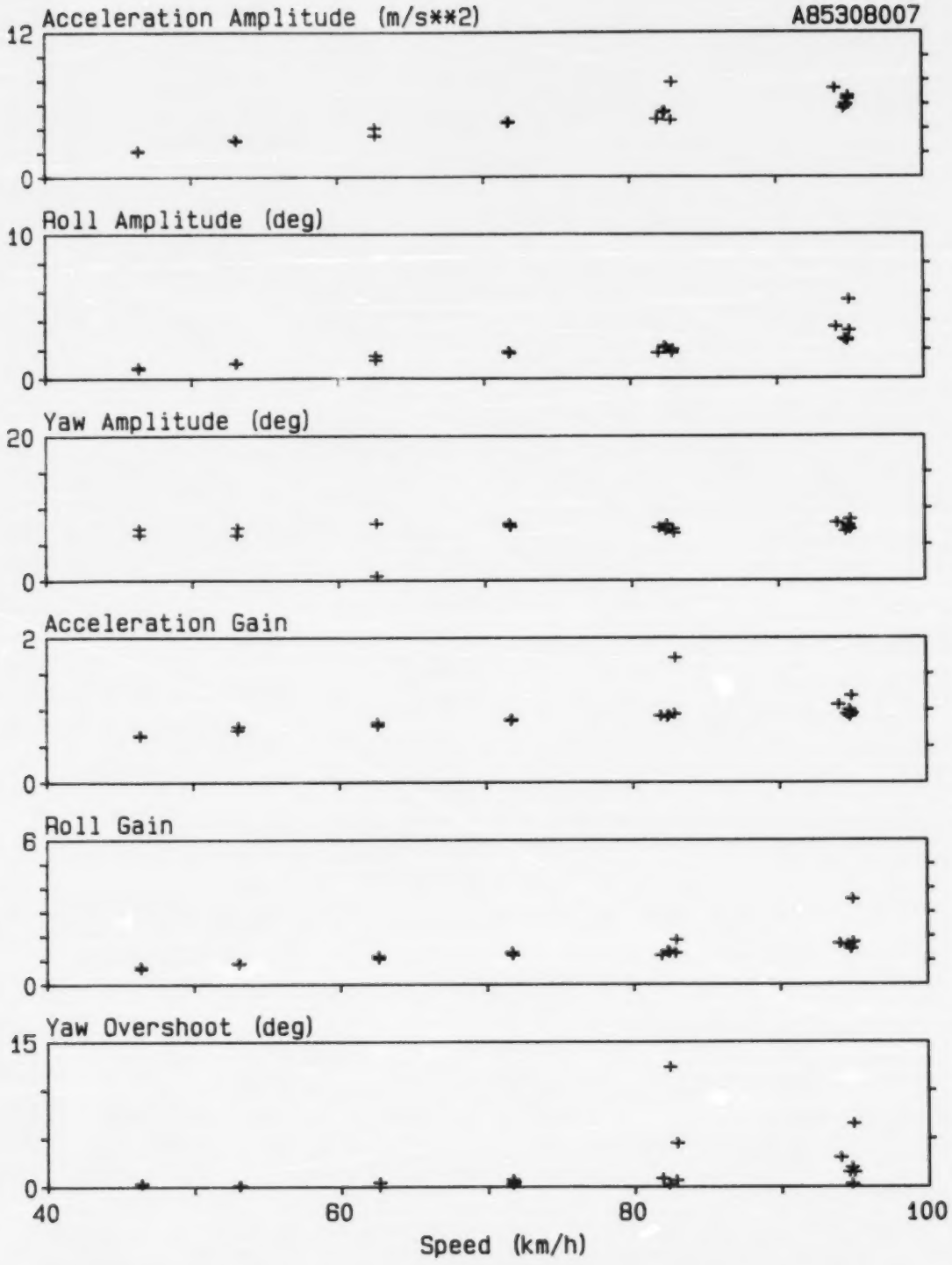


Figure 19/ 45 ft Semi. Lane Change,

Response Summary vs Speed

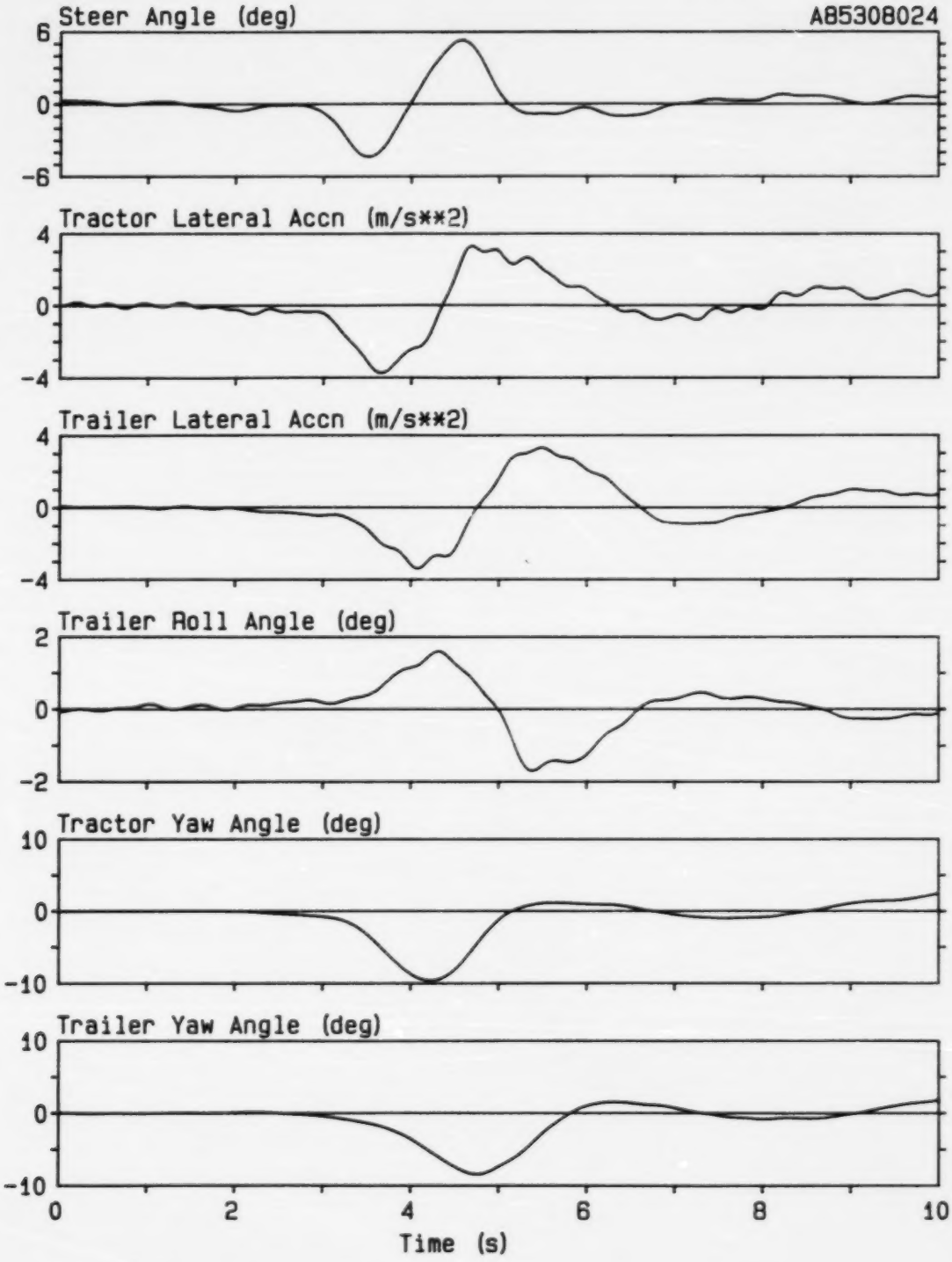


Figure 20/ 45 ft Semi, Lane Change,

Vehicle Responses at 94 km/h

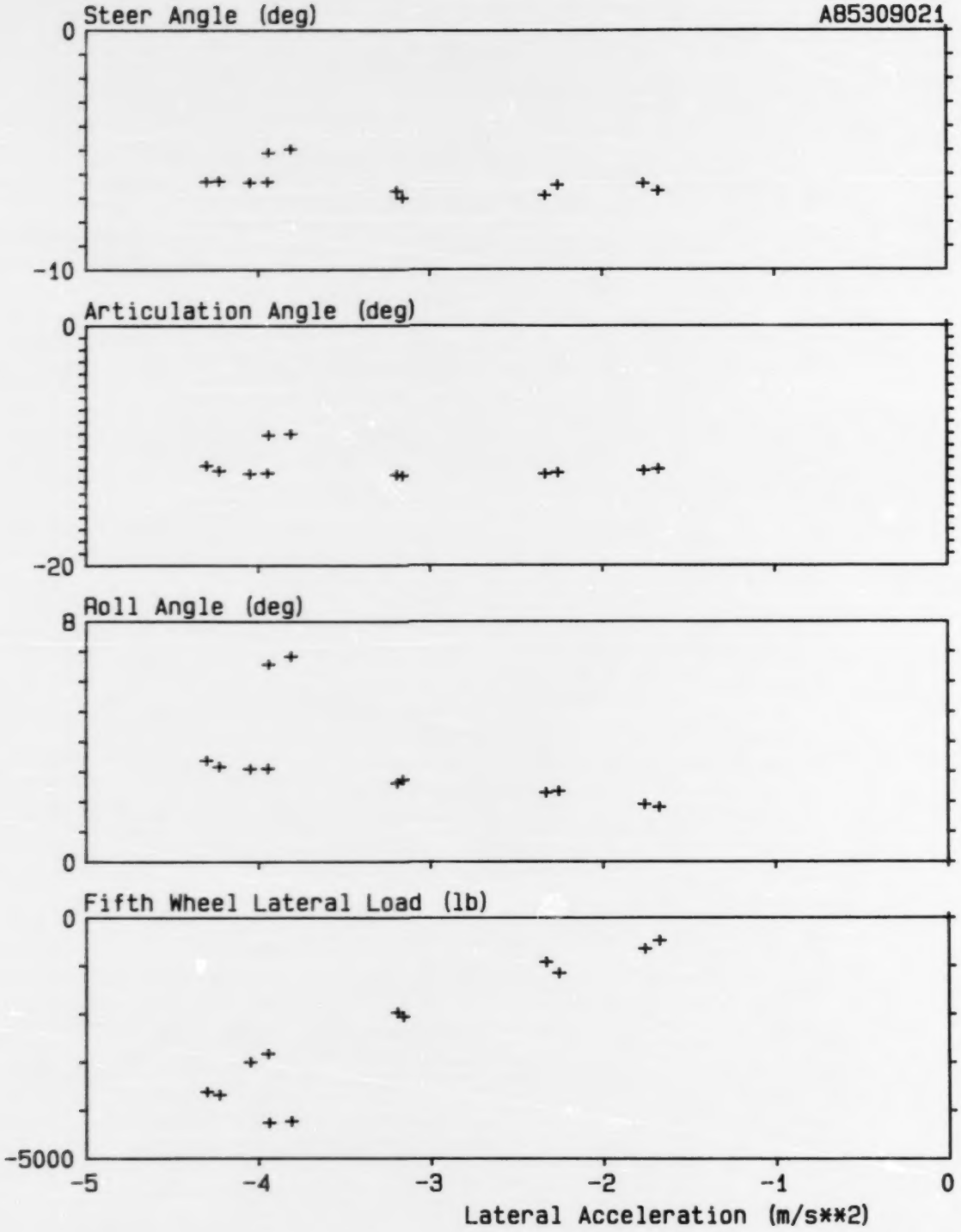


Figure 21/ 45 ft Semi, Steady Circular Turn,
Vehicle Responses vs Tractor Lateral Acceleration

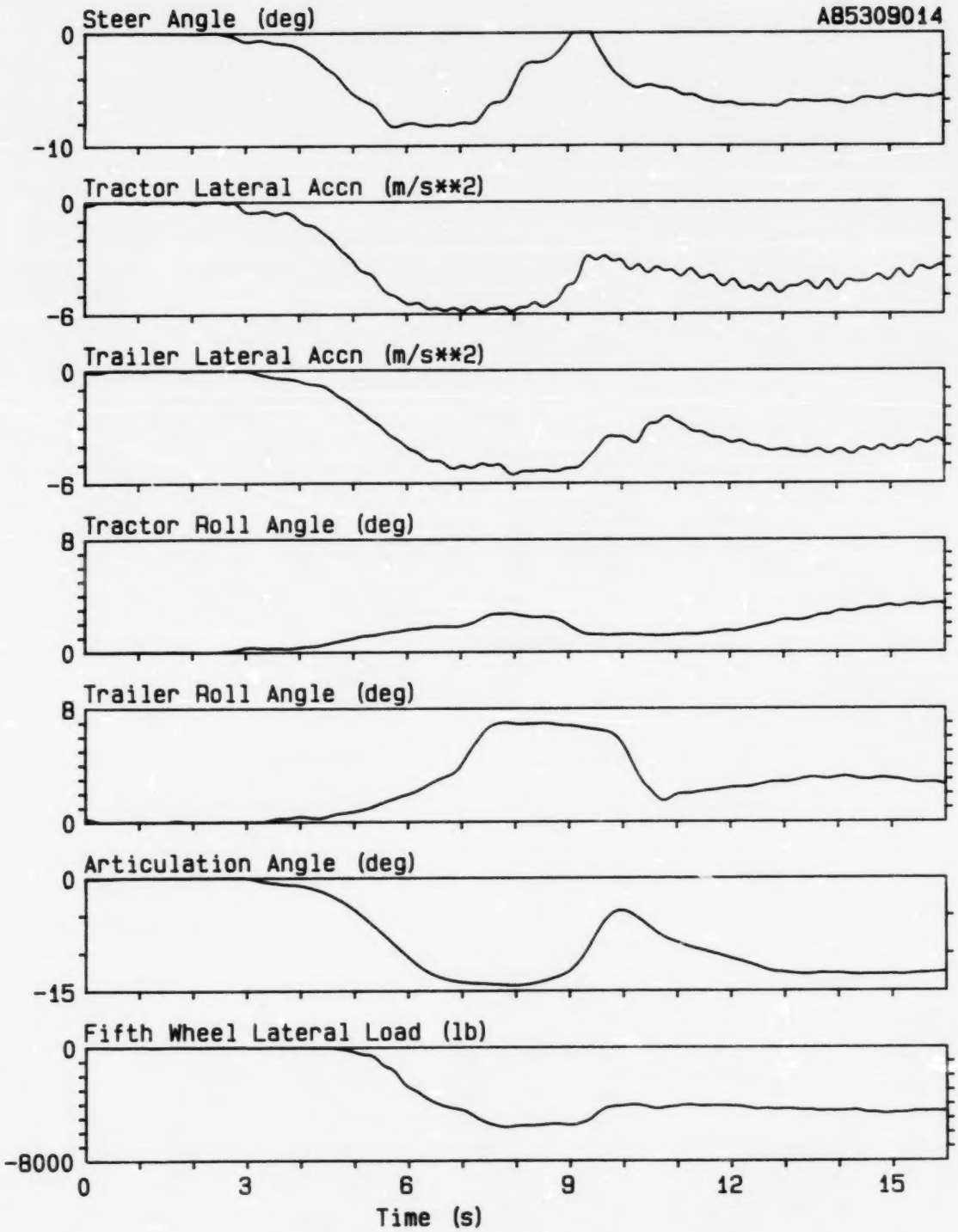


Figure 22/ 45 ft Semi, Steady Circular Turn,
Vehicle Responses at 62 km/h

Figure 23/ 45 ft Semi Vehicle Making
Steady Circular Turn

Figure 24/ 45 ft Semi Vehicle on Tilt Table